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ABSTRACT

The concept of relational complexity is applied to explain the persistent difficulties of young children with theory of mind. Relational complexity has been found useful as a general cognitive complexity metric. Children must understand that the relation between an object and a person's percept is conditional on a third variable, such as a filter or other condition that affects a person's knowledge state. Processing three interacting variables is equivalent to a ternary relation, and this level of complexity is often difficult for young children. It was hypothesized that if relational complexity is a factor in concept of mind, it should be related to tasks at the same level of complexity in other domains. Forty-eight 3- to 5-year-olds were tested on four false belief tasks and on four appearance-reality tasks. They were also assessed on transitivity, hierarchical classification,, and cardinality tasks that had previously been shown to require the same level of relational complexity. Results indicate that the performance of 3-year-olds was significantly lower than the older age groups on both the theory-of-mind and relational complexity tasks. The findings support the relational complexity interpretation of concept of mind. (Author/EMK)

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Relational Complexity and Theory-of-Mind

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Abstract

Some recent attempts to explain the persistent difficulties of young children with theory of mind have focused on the complexity of the task. This research approached the problem through the concept of relational complexity, which has been found useful as a general cognitive complexity metric. Children must understand that the relation between an object and a person's percept is conditional on a third variable, such as a filter or other condition that affects a person's knowledge state. Processing three interacting variables is equivalent to a ternary relation, and this level of complexity is often difficult for young children. It was hypothesised that if relational complexity is a factor in concept of mind, it should be related to tasks at the same level of complexity in other domains. Forty-eight 3- to 5-year-olds were tested on four false belief and on four appearance-reality tasks. They were also assessed on transitivity, hierarchical classification, and cardinality tasks that had previously been shown to require the same level of relational complexity. Results indicated that the performance of 3-year-olds was significantly lower than the older age groups on both the theory-of-mind and relational complexity tasks. A multiple regression analysis revealed that the relational complexity tasks could account for 85% of the age-related variance and a further 11.6% of variance independent of age. The findings support the relational complexity interpretation of concept of mind.

Relational Complexity and Theory-of-Mind

Some recent attempts to explain young children's persistent difficulties with concept of mind have focused on the complexity of the task (e.g., Frye, Zelazo, & Palfait, 1995). Our research approached the problem through the concept of relational complexity, which has been found useful as a general cognitive complexity metric (Halford, 1993; Halford, Wilson, & Phillips, in press). Children must understand that the relation between an object and a person's percept is conditional on a third variable, such as presence of a filter or other condition that affects a person's knowledge state. Processing three interacting variables is equivalent to a ternary relation, and this level of complexity is often difficult for young children. It was hypothesised that if relational complexity is a factor in concept of mind, it should be related to tasks at the same level of complexity in other domains.

Relational Complexity metric (Halford, et al., in press)

Relational complexity refers to the arity of relations (i.e., number of arguments or entities related). Each argument corresponds to a dimension and an *N*-ary relation is a set of points in *N*-dimensional space. The number of dimensions corresponds to the number of interacting variables that constrain responses or decisions. A relational complexity metric is defined. Unary relations have a single argument as in class membership, dog(fido). Binary relations have two arguments as in larger-than(elephant, mouse). Ternary relations have three arguments as in addition(2,3,5). Quaternary relations such as proportion have four interacting components as in 2/3 = 6/9. Quinary relations entail five interacting components. Processing load increases with complexity. However, complexity can be reduced by segmenting the task into several less complex steps which can be processed in succession, or by chunking which can result in loss of information about relations among entities. Normative data suggests that children

process unary relations at a median age of 1 year, binary relations at 2 years, ternary relations at 5 years, quaternary relations at 11 years.

Relational Complexity Analyses

Appearance-Reality. These tasks entail representing the relation between the attributes of an object (object-attribute) and a person's knowledge (percept). Representing the fact that there are two conflicting ways of seeing an object requires that the binary relation between object-attribute and percept be conditionalised on a third variable, viewing condition (e.g., presence or absence of a filter). Children readily understand the component binary relations between object-attributes and percepts, however they cannot integrate them into a single representation. This involves representing the ternary relation:

Seen-Object(viewing-condition, object-colour, percept)

Instances of this relation are:

Seen-Object(no-filter, object-white, percept-white)

Seen-Object(blue-filter, object-white, percept-blue)

False Belief. These tasks entail representing the relation between an object and two representations of its location, one based on knowledge, the other based on a false belief. For example, a person might see an object placed in box, then leave the room, and the object is shifted to a basket. Representing two conflicting representations of an object's location requires that the binary relation between actual-location and believed-location be conditionalised on a third variable, known event (whether the person knows the object was moved). This involves representing the ternary relation:

Find-Object(known-event, actual-location, believed-location)

Instances of this relation are:

Find-Object(saw-moved, object-in-box, object-in-basket)

Find-Object(not-seen-moved, object-in-box, object-in-box)

In our previous research (Andrews, 1997) we have developed tasks in domains including transitivity, cardinality and hierarchical classification, that require ternary relations to be represented.

Transitivity. Transitive reasoning is demonstrated when an inference A *R* C is deduced from premises A *R* B and B *R* C, where *R* is a transitive relation, and A, B, C are the elements related. Determining the relation between A and C involves integrating premises A *R* B and B *R* C to construct an ordered triple, A *R* B *R* C, and has the complexity of a ternary relation.

Cardinality. Understanding of cardinal value and the conditions under which it changes (change in numerosity of set) and remains the same (repetition of count; nonstandard counting order) entails recognition of the relations between a set and a minimum of two component subsets. A ternary relation is involved because three sets must be represented.

Hierarchical Classification. Inferences based on classification hierarchies require recognition of the asymmetric nature of the relations between a superordinate class and two or more non-empty subclasses (Markman & Callanan, 1984). Asymmetry exists because all members of a subclass are included in the superordinate class, but not all members of the superordinate class are included in a particular subclass. This entails the relations among three classes (superordinate, subclass 1, subclass 2), so complexity is equivalent to a ternary relation.

We predicted that performance on Appearance-Reality and False Belief tasks would improve with age and exceed chance level by 5 years of age. Furthermore, performance on Transitivity, Cardinality, and Hierarchical Classification should predict performance on COM tasks, and account for age related variance in COM.

Method

Participants

There were 16 × 3-year-olds (mean age, 43 months, range, 38-47 months), 16 × 4-year-olds (mean age, 55 months, range, 49-59 months), and 16 × 5-year-olds (mean age, 65 months, range, 60-71 months).

General Procedure

All children completed Appearance-Reality (4 tasks), False Belief (4 tasks), Transitivity, Cardinality, and Hierarchical Classification.

Appearance-Reality tasks

Fish-filter (Flavell, Flavell, & Green, 1983). Children were shown a white cardboard fish covered by a blue filter so the fish appeared blue. The filter was removed revealing that the fish was actually white. Children identified the colour of the fish and were given feedback as to the correct colour. The fish was then returned to its original deceptive state.

Appearance *When you look at this with your eyes right now does the fish look blue or does it look white?*

Reality *What colour is the fish really and truly? Is it white or is it blue?*

Skewer in glass (Gopnik & Astington, 1988). Children were shown a skewer (stick). The skewer was placed in a glass of water touching the bottom at a 45 degree angle making it appear bent.

Appearance *When you look at this with your eyes right know, does this stick look bent and crooked or does it look straight?*

Reality *What is this stick really and truly? Is it straight or is it bent and crooked?*

Crayon Box (Frye et al., 1995). Children were shown a crayon box. It was assumed they would initially represent the contents incorrectly (crayons). They were shown the actual contents (sticks) and asked to identify them. The box was then closed.

Appearance *When you look at this box with your eyes right now, what does this box look like it has in it, sticks or crayons?*

Reality *What's really and truly in this box, sticks or crayons?*

Milk-filter (Flavell, Green, & Flavell, 1986). Children were shown milk being poured into a glass that was wrapped in a red filter.

Appearance *When you look at this milk with your eyes right now, does it look red or does it look white?*

Reality *What colour is the milk really and truly? Is it white or is it red?*

False Belief tasks

Smarties box (Perner, Leekam, & Wimmer, 1987). Children were shown a smarties box. It was assumed the child would initially represent the contents incorrectly (smarties). They were shown the actual contents (pencils) and were asked to identify them. The box was closed.

Belief *If someone came into this room right now and had not seen what was inside the box. What would they think was in it, smarties or pencils?*

Reality *What is really and truly in the box, pencils or smarties?*

Colour (Gopnik & Astington, 1988). Children were shown a white cat covered by green transparent plastic so the cat appeared green. The plastic was removed, revealing that the cat was actually white. It was assumed that children would initially represent the cat as green and then represent it as white. They were asked the colour of the cat. The cat was returned to its original deceptive state.

Belief *When you first saw the cat, all covered up like this, what colour did you think the cat really was, green or white?*

Reality *What colour is the cat really and truly, green or white?*

Sam's Puppy (Siegal & Beattie, 1991). Children were told, *Sam wants to find his puppy. Sam's puppy is really in the kitchen. Sam thinks his puppy is in the bathroom.*

Belief *Where will Sam look first for his puppy, the bathroom or the kitchen?*

Reality *Where is the puppy really, the bathroom or the kitchen?*

Chocolate hiding (Wimmer & Perner, 1983). Children were told a story about a boy (Maxi) who went shopping with his mother and bought some chocolate. When they arrived home Maxi put the chocolate into the blue cupboard and went outside to play. While Maxi was away his mother moved the chocolate from the blue cupboard to the green cupboard. She then went to talk to the neighbour. Maxi came in and wanted some chocolate. He still remembered where he had put the chocolate.

Belief *Where will Maxi look first for the chocolate, in the blue cupboard or in the green cupboard?*

Reality *Where is the chocolate really and truly, in the blue cupboard or the green cupboard?*

Transitivity

Materials Premise displays consisted of four pairs of coloured squares in which one colour was higher than another. The four pairs together defined a unique vertical ordering of five coloured squares in a tower. For the example shown in Figure 1, the correct top-down order is red, blue, green, purple, yellow. More generally A > B > C > D > E where A is top position and E is bottom. A different assignment of colours to ordinal positions was used on each trial. Sets of five coloured squares for tower construction.

Procedure In the binary relation control items, children constructed 5-square towers, beginning with an internal pair, either BC or CD. Ordering elements B and C, required consideration of a single premise, B *above* C, and is equivalent to a binary relation. Adding each subsequent square (e.g., D) required consideration of a single premise, C *above* D.

In the ternary relation items, children predicted which of two squares (positions B and D) would be higher up in the tower. Two premises, B *above* C and C *above* D must be integrated to form the ordered set, B *above* C *above* D, from which B *above* D can be concluded. As a check on guessing, C was placed after B and D. If the child had integrated BC and CD to conclude B *above* D, the correct position of C (between B and D) should have been apparent. Credit was given for responses where B, D, and C were placed correctly. Scores were based on ternary relation items (max = 8).

Cardinality

Materials Each of the 12 stimulus displays consisted of four, five or seven pictures of trees, ducks, frogs, or pigs.

Procedure The displays were presented in random order. For each display, children counted the stimuli then responded to one of four question types: *How many; Repetition; Order irrelevance; Subtraction.*

How many (stimuli) are there?

How many (stimuli) would there be if you counted them again?

How many (stimuli) would there be if you counted from the other end?

How many would there be if you counted them again, without this one?

Children were credited with success on the *How many*, *Repetition*, and *Order irrelevance* questions if they restated their count total without recounting the stimuli. Success on the *Subtraction* questions required a response that was one less than the count total, without recounting the stimuli. The *How many*, *Subtraction*, *Repetition*, and *Order irrelevance* scores were summed to obtain a total *Cardinality* score (max = 12).

Hierarchical Classification

Materials. The displays each consisted of eight coloured shapes in which the colour and shape categories overlapped to form two inclusion hierarchies. In the display shown in Figure 2, the superordinate classes (and subclasses) are *squares* (*blue* and *red*); and *blue things* (*squares* and *circles*). Displays used for binary relation control items were similar except that the colour and shape categories did not overlap.

Procedure. Children evaluated statements made about the displays by a toy frog. Example statements are shown in Figure 2. Complexity analyses revealed that the false items were critical. Scores were based on false items for the ternary displays (max = 8).

Results

Each Appearance-Reality and False Belief task entailed two questions. Credit was given if both questions were answered correctly. Table 1 shows the descriptive statistics for the concept of mind tasks. Analyses of variance revealed that the age effect was significant for the combined COM scores, $F(2,45) = 15.55$, $p < .001$, for Appearance-Reality, $F(1,45) = 14.97$, $p < .001$, and for False Belief, $F(1,45) = 8.62$, $p < .001$. Scheffe tests showed that the combined COM means for all age groups differed significantly from one another. For Appearance-Reality, the 3-year-olds' mean differed from means for each older group. For False Belief, the 3-year-olds' mean differed from the mean for the 4- and 5-year-olds combined.

Table 2 shown the descriptive statistics for the relational complexity tasks for each age group. Analyses of variance revealed significant age effect s for Transitivity, $F(1,45) = 5.75$, $p < .05$, Cardinality, $F(1,45) = 7.82$, $p < .001$, and Hierarchical Classification, $F(1,45) = 3.64$, $p < .05$. Scheffe tests indicated that 3-year-olds' means for Transitivity and Cardinality were significantly lower than the 5-year-olds' means. For Cardinality, the 4-year-olds' mean was also significantly lower than the 5-year-olds'.

Table 3 shown the pairwise correlations among the combined COM scores, the relational complexity tasks and age. Multiple regression was used to examine the extent to which the predictor tasks accounted for age related variance in COM scores. Age, transitivity, cardinality and hierarchical classification together accounted for .61 of the variance in combined COM scores, Multiple $R = .80$, $F(4,43) = 19.08$, $p < .001$. The relational complexity tasks reduced the age related variance from .436 (from correlation matrix) to .067 (unique variance due to age). Therefore the relational complexity tasks

accounted for approximately 85% of age related variance (.37/.436). Table 4 summarises the regression analysis.

Discussion

The performance of 3-year-olds was lower than the older age groups on both the concept-of-mind and relational complexity tasks. Consistent with predictions of the relational complexity metric, only the 5-year-olds performed above chance level on all tasks.

The relational complexity tasks accounted for 85% of the age-related variance in concept-of-mind and a further 11.6% of variance independently of age. The findings support the relational complexity interpretation, that is, the difficulty of concept of mind tasks stems from their complexity (ternary relation).

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Table 1

Means (SD's) for Appearance-Reality, False-Belief, and Combined Concept of Mind (COM) tasks by Age Group

Age Group	Appearance-Reality (max = 4)	False-Belief (max = 4)	Combined COM (max = 8)
3-year-olds	0.75	1.00	1.75
	(1.06)	(0.82)	(1.57)
4-year-olds	2.00*	1.63	3.63*
	(1.15)	(1.20)	(2.03)
5-year-olds	2.94**	2.56**	5.50**
	(1.18)	(1.15)	(2.07)

Above chance level (25%), *$p < .01$; ** $p < .001$

Table 2

Means (SD's) for Relational Complexity tasks by Age Group

Group	Transitivity (max = 8)	Cardinality (max = 12)	Hierarchical Class (max = 8)
3-year-olds	1.19	2.19	4.63
	(1.17)	(1.80)	(2.40)
4-year-olds	2.00*	2.81	4.75
	(1.16)	(2.61)	(1.88)
5-year-olds	2.81**	5.63	6.25***
	(1.68)	(3.24)	(1.29)

Above chance level = 1.32 (transitivity); 4 (hierarchical classification)

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 3

Correlations among COM, Age and Relational Complexity tasks

	COM	Transitivity	Cardinality	Hierarchical Class
Age	.66***	.49***	.52***	.33*
COM		.62***	.66***	.41**
Transitivity			.59***	.19
Cardinality				.27

*$p < .05$; **$p < .01$; ***$p < .001$ (two-tailed)

Table 4

Multiple Regression with combined COM (criterion) and Age, Transitivity, Cardinality, and Hierarchical Classification (predictors)

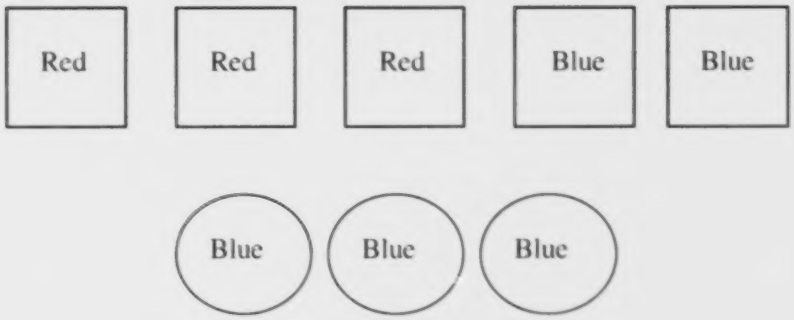
Variable	Beta	Part Corr	sr^2	*t*	Sig. *t*
Age	.32	.26	.07	2.83	.01
Transitivity	.25	.20	.04	2.16	.04
Cardinality	.30	.23	.05	2.49	.02
Hierarchical Class	.17	.16	.03	1.74	.09

Figure Captions

Figure 1. An example premise display for the transitivity task

Figure 2. An example display used for ternary relation hierarchical classification items with relevant questions.

Blue	Red	Green	Purple
Green	Blue	Purple	Yellow



Some -All statements

All the squares are red. (False)
All the circles are blue. (True)

Alternate statements

Froggie picks up all the circles. He says "I have red ones and blue ones." (False)
Froggie picks up all the squares. He says "I have red ones and blue ones." (True)